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Environmental Effects of Dredging Technical Notes

Risk-based Testing of Dredged Material for Aquatic Disposal Evaluations

Purpose

This technical note describes a risk-based framework for testing and evaluating dredged material scheduled for open-water disposal.

Background

In 1989, the Environmental Advisory Board (EAB) recommended to the Chief of Engineers that risk assessment methods be incorporated into the Corps' dredging program. The Chief accepted these recommendations the following year (Anonymous 1990). To examine the feasibility of incorporating risk-based assessment technologies, a review of the risk assessment process was recently conducted (Dillon 1992). This technical note describes an approach for using risk-based test methods in the regulatory evaluation of dredged material being considered for open-water disposal.

Additional Information

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Current Dredged Material Testing and Evaluation

The Corps' statutory authority for the transport and disposal of dredged material into the ocean or waters of the United States comes, respectively, from

section 103 of the Marine Protection, Research, and Sanctuaries Act of 1972 (Public Law 92-532) and section 404(b)(1) of the Federal Water Pollution Control Act of 1972 (Public Law 92-500), as amended. Both laws require that there shall be "no unacceptable adverse impacts" on the environment. This statutory language implies that some "adverse impacts" resulting from dredging operations are permitted as long as they are not "unacceptable." These evaluative criteria strongly suggest a risk-based approach for identifying acceptable "adverse impacts" and when "unacceptable adverse impacts" may be anticipated.

However, contaminant testing of dredged material for aquatic disposal allows only a quantal response (U.S. Environmental Protection Agency (EPA) and U.S. Army Corps of Engineers (USACE) 1991); that is, after testing, the material is classified as either suitable for open-water disposal or not suitable. Intermediate judgments are not possible with the current test procedures. The dredged material manager does not have the technical basis for deciding to what degree the project material is "acceptable" or "unacceptable." Instead, the manager must rely on "best professional judgment" to fill the technical void and provide the necessary managerial flexibility. Rightly or wrongly, the Corps has been severely criticized for what is perceived by some as an overreliance on "best professional judgment" and a decision-making process that is too flexible.

Advantages of Risk-based Assessment Methods

The need for a risk-based approach to testing dredged material can be found in the milieu of Corps' decision-making:

- A regulatory decision will always be made.
- This decision will always be based on incomplete data.
- Data which are available will always have some uncertainty.
- Everyone will accept a certain level of risk and uncertainty.
- Achieving zero environmental risk is not possible.
- Managing for near-zero risk is often cost-prohibitive.

Ultimately, a decision regarding specific project dredged material will be made and documented in the Record of Decision (ROD). This decision must be justified but should not be qualified. That is, the ROD should read "Yes, because . . ." or "No, because . . ." not "Yes, but . . ." or "No, but . . .". The justification supporting the regulator's decision presently relies heavily on "best professional judgment." Risk assessment offers a technically sound, quantitative alternative to best professional judgment. It would provide the decision-maker with estimates of environmental risks allowing the decision-maker to balance risks with potential benefits and would also permit the relative risks associated with different management options to be evaluated (USEPA and USACE in preparation).

Another advantage of risk-based assessments is that they address uncertainties explicitly. Instead of ignoring the uncertainties associated with *all* data sets, risk assessments are designed and conducted in a way which quantitates this uncertainty. Technical findings of a risk assessment are expressed in terms of probability statements. In contrast, current dredged material test methods appear as quantal statements. Expressing results as probability distributions recognizes the uncertainties involved and provides a quantitative framework for managerial flexibility (Morgan 1984 and Finkel 1990).

A risk-based approach to testing, therefore, can provide the dredged material manager with a more rational basis for decision-making where subjective evaluations are required. Test results are expressed as a continuum of alternative solutions, each with its own probability of adverse environmental impact. It was these characteristics of risk assessment and the Corps' decision-making environment which prompted the EAB recommendations.

Synopsis of the Risk Assessment Process

A decade ago, the National Academy of Sciences (NAS) recommended a unified, generic process be used by Federal government agencies to assess the health risks posed by anthropogenic chemicals (National Research Council 1983). The NAS risk assessment paradigm (as it came to be known) has been the blueprint for virtually every risk assessment conducted since that time. While details of individual risk assessments vary, they all contain three major elements — exposure assessment, effects assessment, and risk characterization. In exposure assessment, the spatial and temporal distributions of chemicals and chemical mixtures are determined relative to the target receptor of concern. Effects assessment determines the magnitude of chemical toxicity by conducting dose-response experiments in the laboratory with appropriate test species. The third element, risk characterization, integrates exposure and effects assessment data to produce a numerical estimate of chemical risk. Despite the complex jargon and voluminous publications on the subject, all risk assessments consist of just these three simple elements.

Risk-based Framework for Testing Dredged Material

The framework described below is based on what is known and what knowledge must be acquired. It draws heavily upon existing dredged material test methods and is based on current understanding of the fate and effects of contaminated sediment. The framework also suggests some assessment activities which require additional research and development or have not yet been developed. Topics requiring future evaluation include:

- Quantitative probability-based models accurately simulating in-situ exposures.
- Appropriate experimental designs for generating probability-based exposure-response curves.

- Technically sound interpretive guidance for biologically and ecologically important endpoints which have societal value.
- Models to more closely couple the probability-based exposure and effects information.
- Development of formal uncertainty analysis procedures.
- Procedures for accurately communicating environmental risks to nontechnical audiences.

Exposure Assessment

Exposure assessment determines the spatial and temporal distributions of contaminants or contaminant mixtures. In the environment, these distributions often appear as logarithmic functions. Figure 1 presents a hypothetical example of this type of distribution. Note that the mean, a statistic routinely used to portray data sets, does *not* represent the most probable exposures.

Various types of spatial and temporal exposure distributions are associated with the aquatic disposal of dredged material. High concentrations of suspended material may exist for a very short time (minutes to hours) in the water column immediately following disposal. This type of exposure distribution is characterized as both time- and space-limited. Consequently, the *probability* of exposure is very low. In contrast, exposure to low concentrations of suspended sediment has a higher probability of occurrence. Sediment

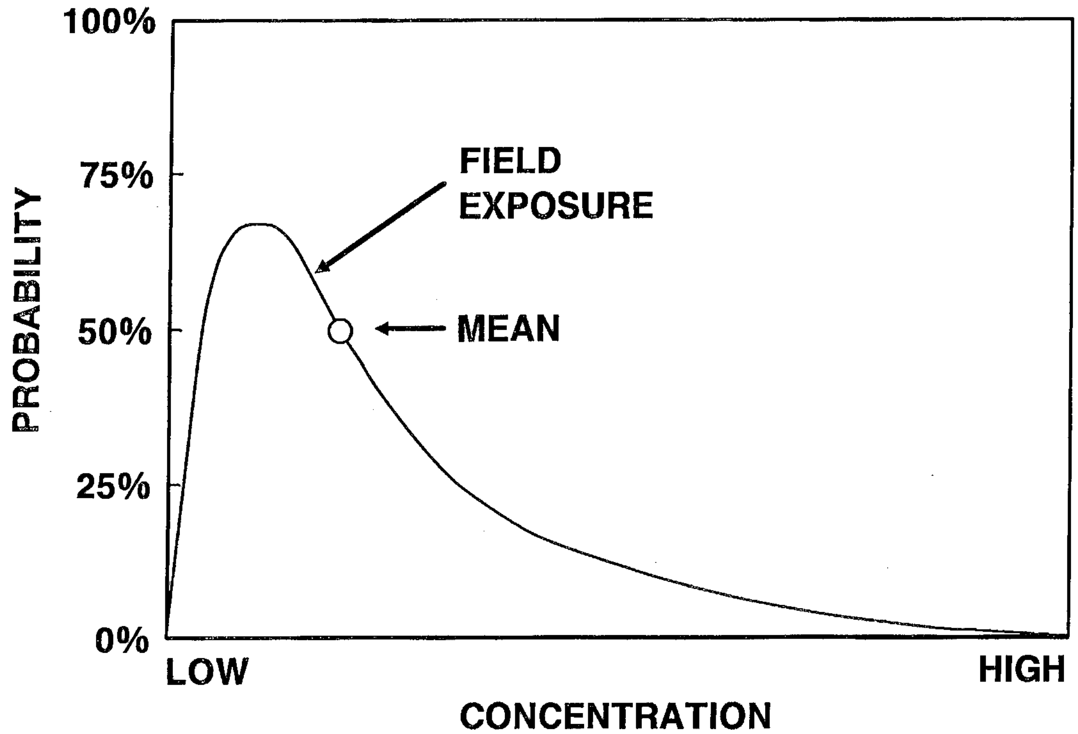


Figure 1. Hypothetical logarithmic probability distribution of environmental contaminants or contaminant mixtures

resuspension may occur frequently and can involve spatially expansive areas. Hence, exposure to low concentrations of suspended sediment is neither time- nor space-limited. A biological component is associated with this latter type of exposure distribution. Many target species of concern (benthic organisms) live at or near the sediment-water interface where sediment resuspension is most intense.

For deposited dredged material, exposure distributions can also vary spatially and temporally. Immediately following point-dump disposal in nondispersive waters, a discrete mound of material is created on the bottom (Germano and Rhoads 1984). However, material can spread outward radially from the central mound, creating a spatially broad yet relatively thin layer of material surrounding the central mound. Over time, the finer grained material may be winnowed out via currents and resuspension events. Thus, the qualitative nature of the deposited sediment exposure will change temporally.

Effects Assessment

In traditional effects assessment studies where human health is the primary concern, laboratory animals are exposed to a range of chemical concentrations and their biological response to each concentration determined. These data are used to construct dose-response curves. The dose-response curve establishes chemical-specific causality and documents the magnitude of chemical toxicity. Laboratory results are then extrapolated in two ways — from the surrogate test species to the target species of concern and from high laboratory concentrations to low environmentally realistic exposures. The first extrapolation is necessary because toxicity tests with the most common target species of concern, *Homo sapiens*, are not possible. High chemical doses are used in the laboratory because statistically significant responses are not detectable at low concentrations. Not surprisingly, both types of extrapolations introduce considerable uncertainty. Appropriate extrapolation models are still debated in the scientific community (Cothern, Coniglio, and Marcus 1986 and Lu and Sielken 1991).

Effects assessment for dredged material differs from the usual chemical-specific approach in several important aspects. One of the most important differences is based on the fact that dredged material is a complex mixture of chemicals. The chemical composition of sediment samples is rarely ever completely characterized. For that reason, establishing chemical-specific causality with dose-response curves is not possible. Instead, sediment exposure is substituted for the chemical dose to produce an exposure-response curve (Figure 2). Sediment exposure-response curves have two distinct advantages over the standard chemical-specific dose-response curve approach. First, because aquatic organisms (not humans) are the primary target species of concern, effects-based testing can be conducted with that species or a phylogenetic sibling. This eliminates the need for extrapolations between disparate species. Second, environmentally realistic sediment exposures can be included in the experimental design (see horizontal axis in Figure 2). This negates the need for extrapolation models estimating low environmentally realistic exposures from high laboratory doses. Eliminating these dubious extrapolations greatly reduces the

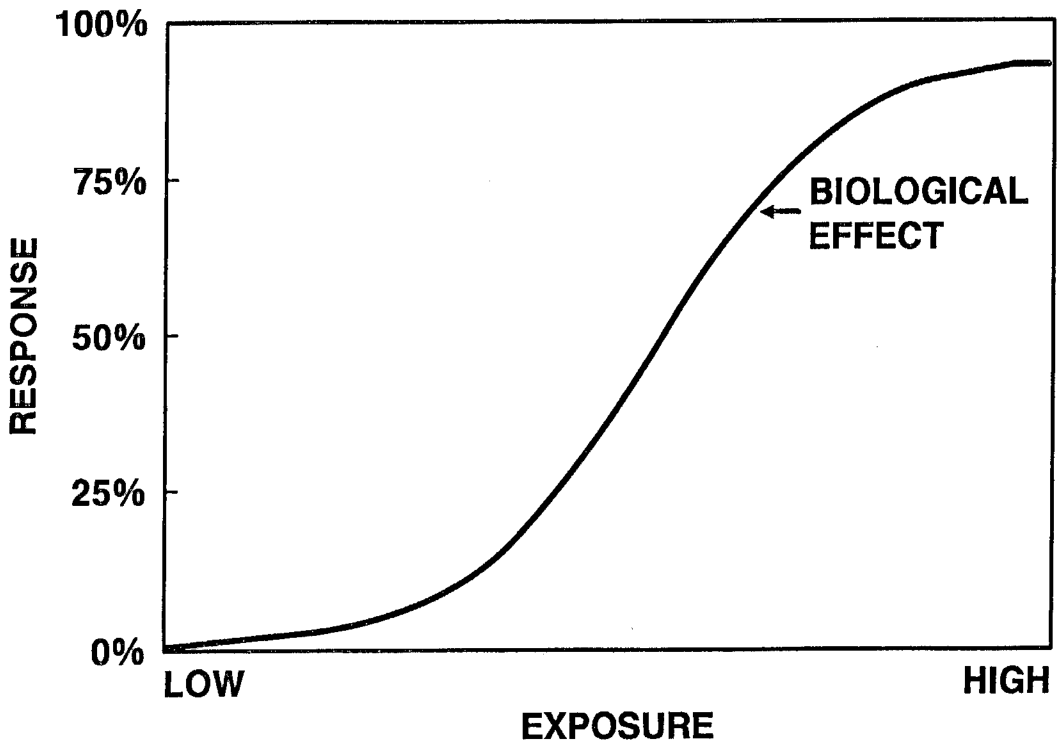


Figure 2. Hypothetical sediment exposure-response curve

uncertainty associated with the sediment exposure-response data and with the subsequent estimate of environmental risk.

Various experimental designs can be used to generate sediment exposure-response curves. For suspended sediments, an exposure gradient can be created in two ways. One approach creates a range of suspended sediment concentrations (mg/L) from a single project sample. The second holds the suspended sediment concentration constant and varies the proportion of project material (for example, 0, 10, 50, or 100 percent). For deposited sediments, a similar approach can be taken by proportionally diluting project sediment with the reference sediment. Alternatively, a known or suspected field gradient can be evaluated by using field-collected sediment samples representing that gradient.

In designing a sediment exposure-response experiment, one must select an appropriate biological response endpoint (see the vertical axis in Figure 2). In the past, sediment bioassays have measured percent survival following acute exposure (≤ 10 days). Most dredged materials, however, are not acutely lethal. Therefore, a new generation of sediment bioassays is emerging which examine more subtle, sublethal endpoints following longer (chronic) sediment exposures (Dillon in preparation). Growth and reproduction are two desirable sublethal endpoints for chronic sediment bioassays (Dillon, Gibson, and Moore 1990). They are sensitive and relatively easy to measure and have high ecological and biological relevance. They have the added advantage of being easily understood by the public. The disadvantage of sublethal endpoints is the lack of

technically sound interpretive guidance. While death is easy to discern and interpret, sublethal endpoints encompass a range of responses and each requires a slightly different interpretation. For example, what is the significance of a 5 percent decrease in growth? Is a 10 percent decrease twice as bad or just marginally worse? Interpretive guidance to answer these questions must be generated before chronic sublethal sediment bioassays can be fully used.

Risk Characterization

The exposure and effects assessment information is combined in the last stage of the risk assessment process — risk characterization. This technical integration produces an estimate of environmental risk (Figure 3). Figure 3 was created by superimposing Figure 1 onto Figure 2. One can use this information to project the probability of potential impacts. For example, in the hypothetical data set, the most probable field exposure will occur with a frequency of about 65 percent (Figure 4a). Because this exposure is associated with a very low probability of adverse impacts (≅ 2 percent), one concludes that the environmental risk is very low. The average or mean field exposure (Figure 4b) is associated with a slightly higher incidence of adverse effects (≅ 5 percent). At the other end of the spectrum (Figure 4c), a very high frequency of adverse biological effects (≅ 100 percent) is associated with sediment exposures that are very rare (≅ 2 percent). Whether these sediment-induced adverse impacts are judged "acceptable" or "unacceptable" depends on the interpretive guidance used to explain the biological and ecological importance of test results.

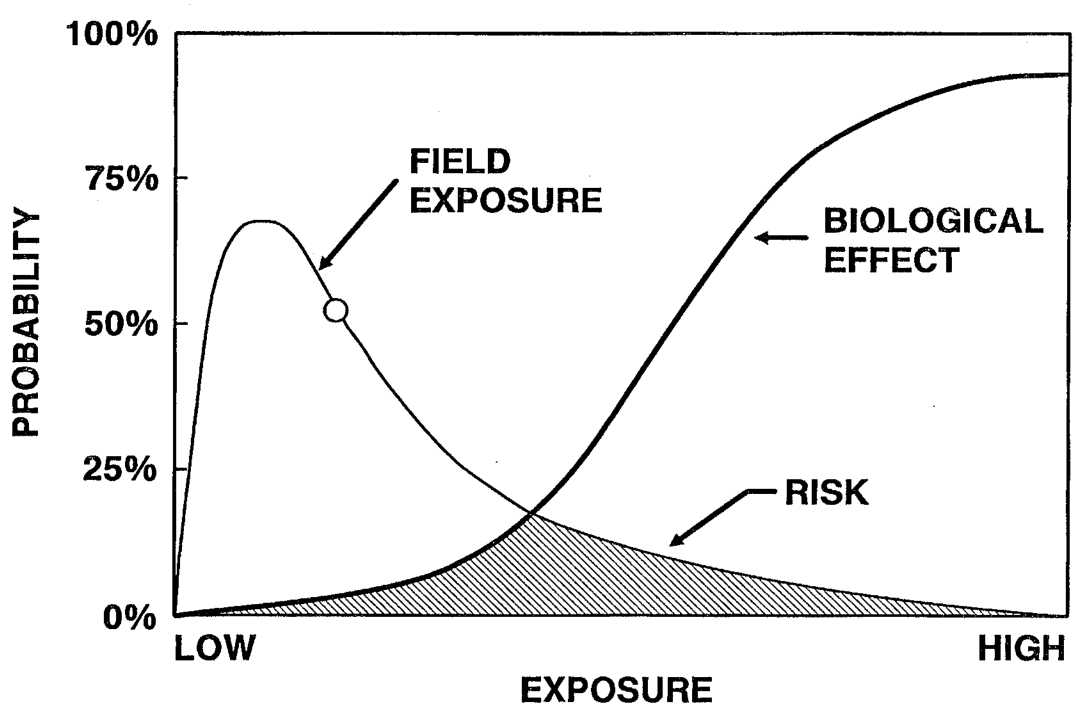
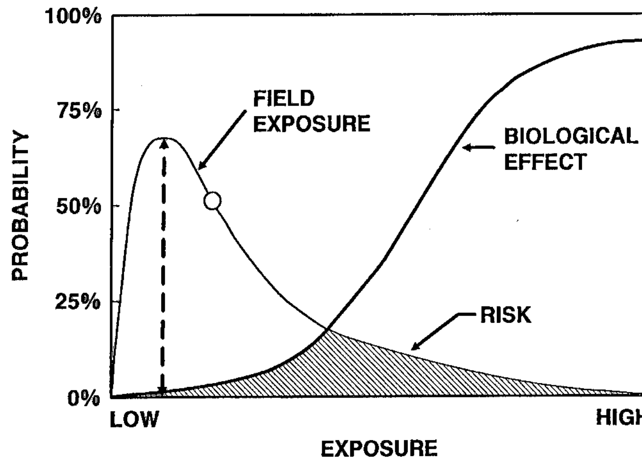
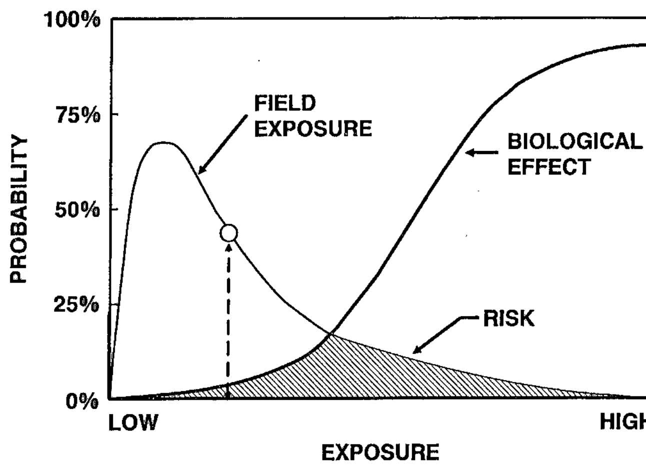


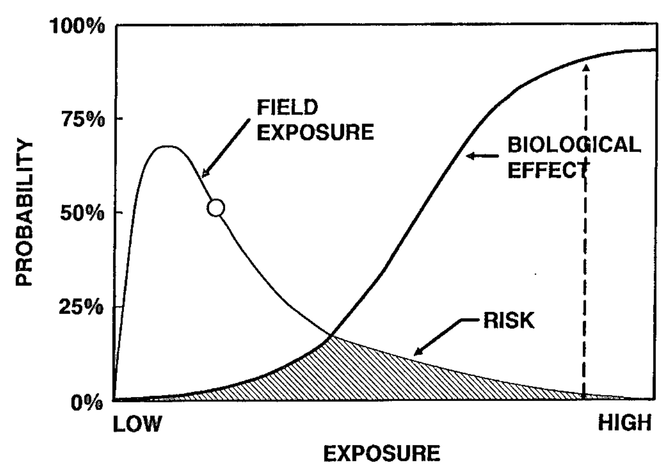
Figure 3. Technical integration of exposure assessment and effects assessment information to yield estimates of probable environmental risk (hatched area)



a. Highest probability event



b. Average probability event



c. Lowest probability event

Figure 4. Use of exposure assessment and effects assessment information to project the relationship between exposure event probabilities and their associated biological effects

Risk-based Management of Dredged Material

Once risk-based dredged material testing has been completed, possible management alternatives are evaluated. These can range from no action to extensive (and perhaps expensive) management. All chemical risks are managed by controlling exposure. This includes contaminated sediments. The intrinsic toxicity of dredged material (that is, the exposure-response curve in Figure 2) can rarely, if ever, be altered.

One popular and effective management technique for deposited dredged material is capping (Shields and Montgomery 1984, Brannon, Hoeppel, and Gunnison 1987, and Palermo in preparation). Project material found to be initially unacceptable for open-water disposal is covered with a cap of acceptable material. This cap physically isolates the unacceptable material and, by reducing the contaminant exposure potential, renders it acceptable. This reduction is shown graphically (Figure 5) using the previous example. Similar risk-based comparisons can be carried out to evaluate other management alternatives such as confined disposal areas or even the no action alternative. Exposure to contaminants in the water column may be reduced by managing the frequency, location, or volume of material disposed. Risk-based technical evaluations also facilitate the weighing and balancing of potential environmental impacts with other management considerations, such as engineering feasibility,

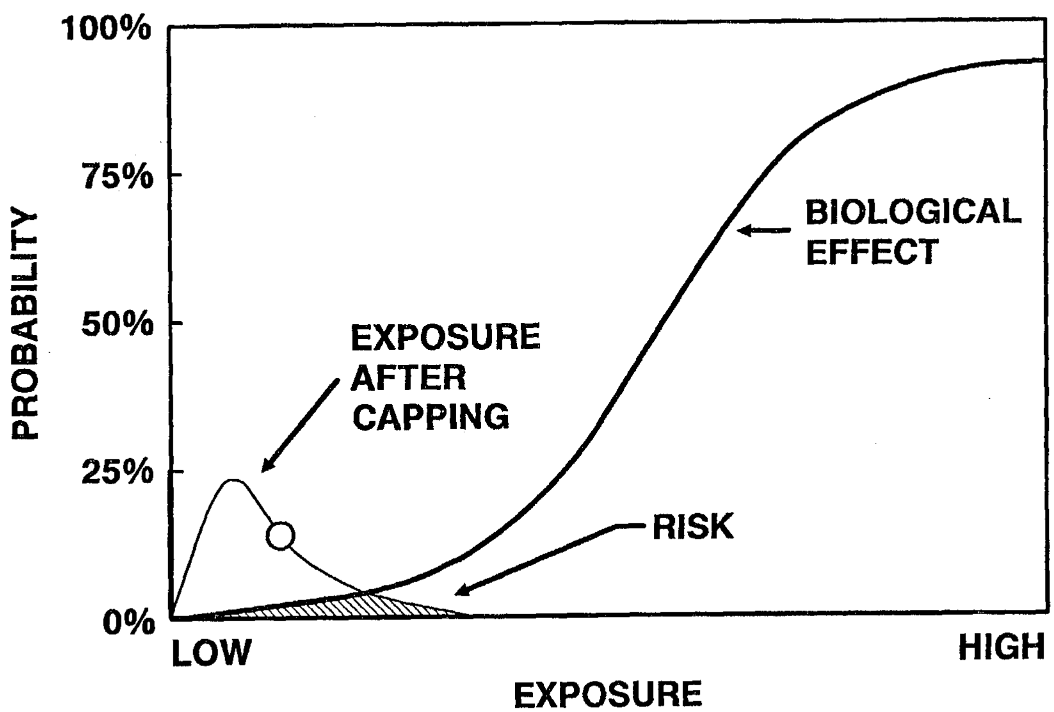


Figure 5. Use of exposure assessment and effects assessment information to quantify the reduction in environmental risk achieved through capping

benefits, and costs. Even qualitative considerations, such as the socio-political decision-making environment, would be facilitated with risk-based testing.

In the future, the Corps will probably become intensively involved in environmental or cleanup dredging. The Corps has three separate authorities for conducting this type of nonnavigational dredging. The oldest, but least used, is section 115 of the Federal Water Pollution Control Act of 1972 (Public Law 92-500). The second, more familiar authority is the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or Superfund. The 1986 reauthorization of this law, (Superfund Amendments and Reauthorization Act (SARA) (Public Law 99-499)), included the Department of Defense's Defense Environmental Restoration Program (DERP) as section 211. The third authority, also the most recent, is section 312 of the Water Resources Development Act of 1990. Under all three authorities, the Department of Defense and the Corps are required to follow the procedural and substantive assessment techniques recommended by the EPA. The guiding framework for those assessment technologies is environmental risk assessment.

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